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Savings Potential of ENERGY STAR® External Power Adapters and Battery Chargers

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ABSTRACT

External power adapters may lose 10 to 70 percent of the energy they consume, dissipated as heat rather than converted into useful energy. Battery charging systems have more avenues for losses: in addition to power conversion losses, power is consumed by the charging circuitry, and additional power may be needed after the battery is full charged to balance self-discharge.

In 2005, the Environmental Protection Agency launched a new ENERGY STAR® label for external power supplies (EPSs) that convert line-voltage AC electricity into low-voltage DC electricity for certain electronic devices. The specification included power supplies for products with battery charging functions (e.g. laptops and cell phones), but excluded others. In January 2006, a separate specification was issued for battery charging systems contained primarily in small household appliances and power tools. In addition to the ENERGY STAR label, the state of California will implement minimum energy performance standards for EPSs in 2007, and similar standards for EPSs and battery chargers are in development at the national level.

Many of the products covered by these policies use relatively little power and have modest per-unit savings potential compared to conventional energy efficiency targets. But with an estimated 1.5 billion adapters and 230 million battery charging systems in use in the United States, the aggregate savings potential is quite high. This paper presents estimates of the savings potential for external power adapters and battery charging systems through 2025.

Introduction

Consumer electronics—computers, home entertainment, cell phones, iPods, etc.—are a seemingly indispensable part of modern life. Both in the home and on the go, we can't seem to live without our electronic gadgets. U.S. households own an average of 25 consumer electronics products, including an average of 3.1 TVs per household (TWICE 2005). Between 1995 and 2001, the share of U.S. homes with a computer went from 40% (Appliance 1996) to 56% (USDOE 2004). But that's not the whole picture: the number of computers per home was also climbing, with 80 million computers in 60 million homes by 2001 (including desktops and laptops, USDOE 2004).

All those gadgets take energy, and they are responsible for an ever-growing share of our national electricity use. According to a 1996 estimate, electronics made up about 7 percent of U.S. residential electricity (Foster, Calwell & Horowitz 2004).

The Environmental Protection Agency's (EPA) ENERGY STAR® Program has led the way in attempting to reduce the energy consumption of consumer electronics devices. The program gradually added office equipment (PCs, monitors, printers, copiers, fax machines, scanners, and multifunction devices), TVs, VCRs, DVD players, audio equipment, cordless phones and answering machines.

However, while a product-by-product approach worked well for these large, well-defined product classes, it was not practical to develop separate specifications for the many small and diverse products that include external power supplies (EPSs) and battery charging functions. Instead, EPA addressed these products under two wide-reaching specifications. The external power adapter specification covers single-voltage AC-DC or AC-AC power supplies up to 250 watts, but excludes those that charge batteries that directly physically attach to the power supply unit and those that have both a battery chemistry selector switch and an indicator light or state-of-charge meter. Note that this scope includes power supplies used with certain products that charge batteries, including laptop computers, cell phones, cordless phones, and some digital cameras, personal digital assistants (PDAs) and portable digital music players (these last three categories also include devices that are designed to run on alkaline batteries or use chargers covered under the battery charger specification).

The ENERGY STAR battery charging system specification covers battery chargers

1) packaged with portable rechargeable products whose principal output is mechanical motion light, the movement of air, or the production of heat,
2) stand-alone chargers sold with products that use a detachable rechargeable battery, and
3) stand-alone chargers designed for rechargeable batteries that replace standard sized alkaline cells (such as AAA, C, D or 9-volt).

Inductive chargers (used to reduce the possibility of electric shock, as for electric toothbrushes) are excluded from the specification. Please see the ENERGY STAR specifications (EPA 2004 and 2005) for the full list of product definitions and exclusions.

This report provides a brief history of the development of the two specifications and estimates program savings through 2025. Because much has already been published on power supply efficiencies (Calwell & Reeder 2002; Foster, Calwell & Horowitz 2004), we will provide only a summary of EPS issues and policy history while providing greater detail on the development of the battery charging specification. Both groups of products receive equal weight in the savings calculations.

Background

Power Supplies. Many electronic components are designed to operate using low voltage direct current (DC). U.S. homes are wired for 120-volt alternating current (AC). Electronic devices must therefore incorporate power supplies (or power adapters) that convert the AC wall current to the appropriate voltage DC for the device to function. Once electricity has been converted from AC to DC, DC to DC converters can be used within the device to supply appropriate voltages to the various system components. Power supplies can be internal (e.g., in a television or desktop computer) or external. This paper addresses only external power supplies. EPSs may plug directly into an outlet or connect to an outlet with an AC cord.

Power supply efficiency has two components. First is the conversion efficiency, defined as the ratio of the total real output power (DC) of the power supply to the total real input power required to produce it (Calwell et al. 2004). Efficiency varies depending on how much current is being drawn through the device, and a power supply that is efficient at 100% of its rated load may not be efficient at lower levels of current. At very low current draws, efficiency drops toward zero. This is because all power supplies draw some power even when they are not supplying current to a load. This is the second component of power supply efficiency: how much power is used when there is no load. Calwell and Reeder (2002) provide a useful primer on power supply efficiency.

External power supplies are usually detachable from the device they power, and can be replaced with a power supply with the same electrical characteristics (output voltage and current). Because of this, it is possible to pair an electronic device with a more efficient power supply, and reduce the energy consumption of the whole device, without redesigning the device itself.

Interest in external power supplies catalyzed into action when, in 2003, the California Energy Commission's Public Interest Energy Research (PIER) Program funded a project aimed at improving the efficiency of internal and external power supplies. That project led to the development of a test procedure for external power supplies, a critical step in the development of subsequent policies.

In February 2004, Andrew Fanara of ENERGY STAR gave a presentation at the Applied Power Electronics Conference on the need for energy-efficient power supplies and a proposed ENERGY STAR power supply specification. He also announced a design competition, co-sponsored by the PIER program, for energy-efficient power supplies (internal and external). A stakeholder meeting was held in May, attended by power supply and consumer product manufacturers. By August, a test procedure had been finalized and adopted by ENERGY STAR, and in January 2005 EPA began labeling products.

In finalizing the specification, EPA decided to reserve small household appliances for the battery charger specification that they subsequently completed and released in January 2006. This class of products is almost entirely powered by NiCd and NiMH batteries. It turned out that by reserving these products for the battery charger specification they were better able to tailor a specification to how battery chargers use energy, resulting in higher savings than treating these products under the EPS specification.

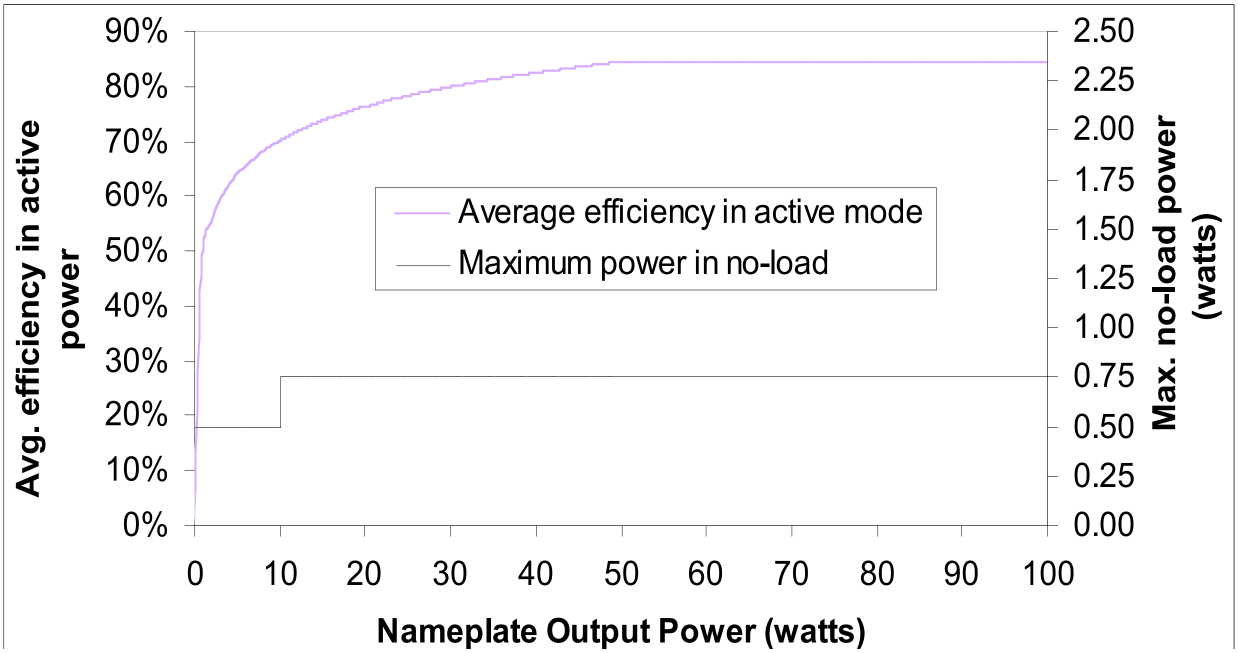
Figure 1 shows the ENERGY STAR criteria for external power supplies, which include a minimum active mode efficiency (measured on the left axis) and a maximum no-load power consumption (on the right axis). The requirements are a function of nameplate output power. See EPA (2004) for the full specification.

The website http://www.efficientpowersupplies.org/ contains extensive information on external power supplies, recent research, and the development of public policies.

Battery Chargers. In developing the battery charger specification, the Cadmus Group, serving as a consultant to EPA, metered a series of products and examined how the energy was used or dissipated. Energy in battery charged products is used for the following purposes:

- Battery charging
  - directly useful energy or "battery energy")
  - additional energy needed to charge battery (Coulombic efficiency)
- Cell equalization (CE)
- Self discharge balance, mainly for NiMH and NiCd batteries (battery maintenance)
  - Required battery maintenance
  - Additional unnecessary energy

Figure 1. ENERGY STAR Efficiency Criteria for External Power Supplies



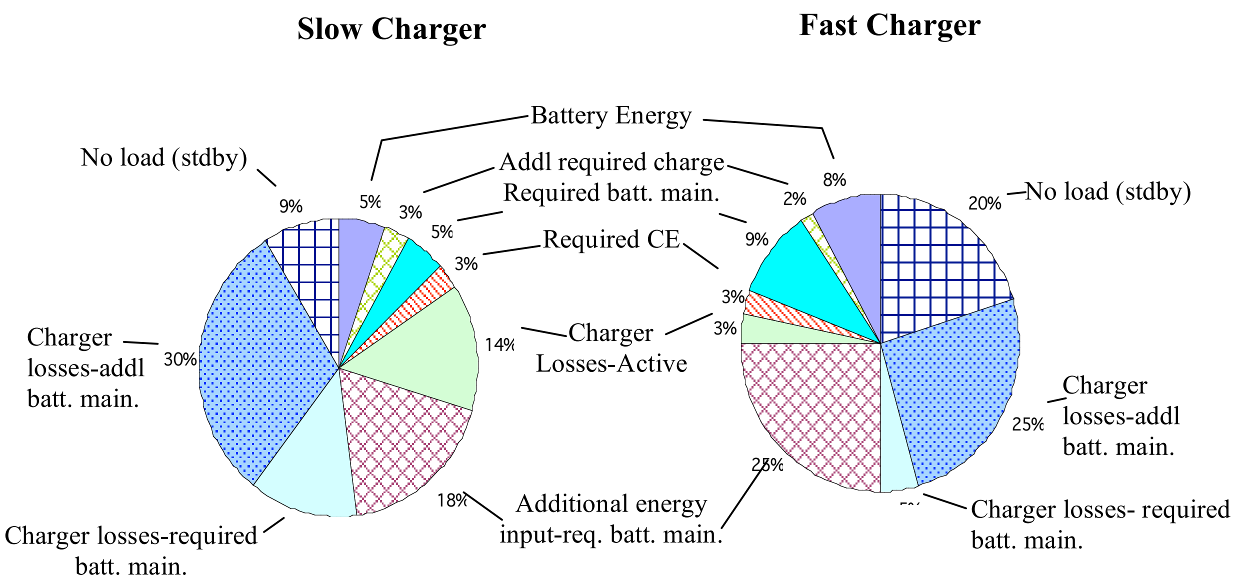
- Losses in power conversion
  - Losses while charging
  - Losses while maintaining the battery
- Standby
  - Used in sensing circuits

To examine the relative proportion of the above energy uses, a rechargeable drill with an EPS-style charger was metered for 1 charge cycle and then left for an additional 36 hours on the charger. For an additional 12 hours, the product and battery were removed from the wall pack style charger, but the charger remained plugged into the AC power source in standby mode. This test was meant to simulate how a tool might be used in a typical household. Figure 2 shows where energy was used in this product for this charge cycle (labeled slow charger in the Figure). Roughly 16 percent of the energy goes into required functions, with half of this needed to charge the battery and the remainder used to ensure that cells are equally charged and that the battery retains its charge. Roughly 18 percent of the energy was supplied in excess to maintain the battery's charge.

This pie chart shows that focusing on losses during active charging of the battery and during standby would only address 25 percent of the energy used. Even cutting these losses in half would save only 12 percent. In contrast, excess battery maintenance energy and losses during battery maintenance account for 61 percent of energy use. Including standby, energy use when the battery isn't charging accounts for 70 percent of energy use.

Similarly, EPA examined the energy use of a fast charger that charged a power tool battery in 1 hour. By necessity, fast chargers deliver a relatively high level of power for a short time then sharply reduce the energy delivered. The relative energy use of this charger is also shown in Figure 2. The energy conversion during charging is more efficient, leaving nearly all

Figure 2. Energy Used in Slow and Fast (1 hour) Chargers for Power Tools



of the losses in the period after the battery is fully charged. In fact, 75 percent of the energy is used after the battery is fully charged.

This energy use pattern for slow and fast chargers led EPA to focus on the energy use of a charger when maintaining a battery and during standby. The rationale was that for slow chargers limiting maintenance energy would also increase charging efficiency. For fast chargers, nearly all losses occur after the charging is complete. An additional factor considered was that many household products spend almost all of their time in battery maintenance mode. Consider floor care products and cordless toothbrushes: both products spend all of their life in a cradle and are used for minutes per week. Once the battery is fully charged, the charger simply delivers a small rate of charge to balance self-discharge.

EPA metered over 100 product and battery combinations recording the battery capacity, and the energy used to charge, and then maintain the battery. After a series of drafts and discussions with various stakeholders, EPA decided on a 48-hour test that started with a fully charged battery, maintained the battery for 36 hours, then operated the charger in standby for an additional 12 hours. While no test could exactly represent how a broad variety of differing products are used, this period was broadly agreed upon. Figure 3 shows the energy use measured in the AC side of the charger graphed against the DC energy capacity of the battery for 65 of the nearly 150 product combinations ultimately tested.

The energy use generally increases with battery capacity, but exhibits a very large range for a variety of reasons including variation in energy conversion, and how well energy use is controlled in battery maintenance modes. Ultimately the data was normalized by dividing energy used over 48 hours of battery maintenance and standby by the measured nominal battery capacity, and graphing this on the battery voltage, as shown in Figure 4. As an interim step the energy ratio was graphed against battery capacity. It turned out that this graph was very similar to the graph against voltage. Ultimately the specification was based on the voltage graph because it allowed a relatively simple specification line to be drawn, and identifying products by battery voltage was relatively straightforward.

Figure 3. AC Energy Use Graphed on DC Battery Capacity

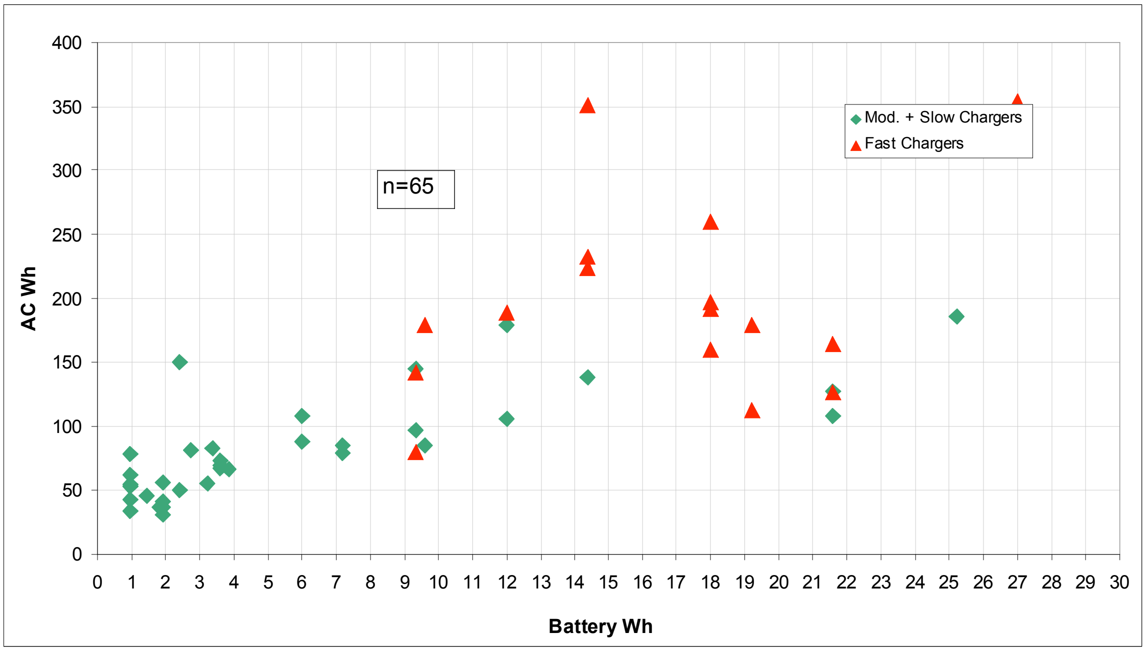


Figure 4. Specification: Energy Use Ratio Graphed on Battery Voltage

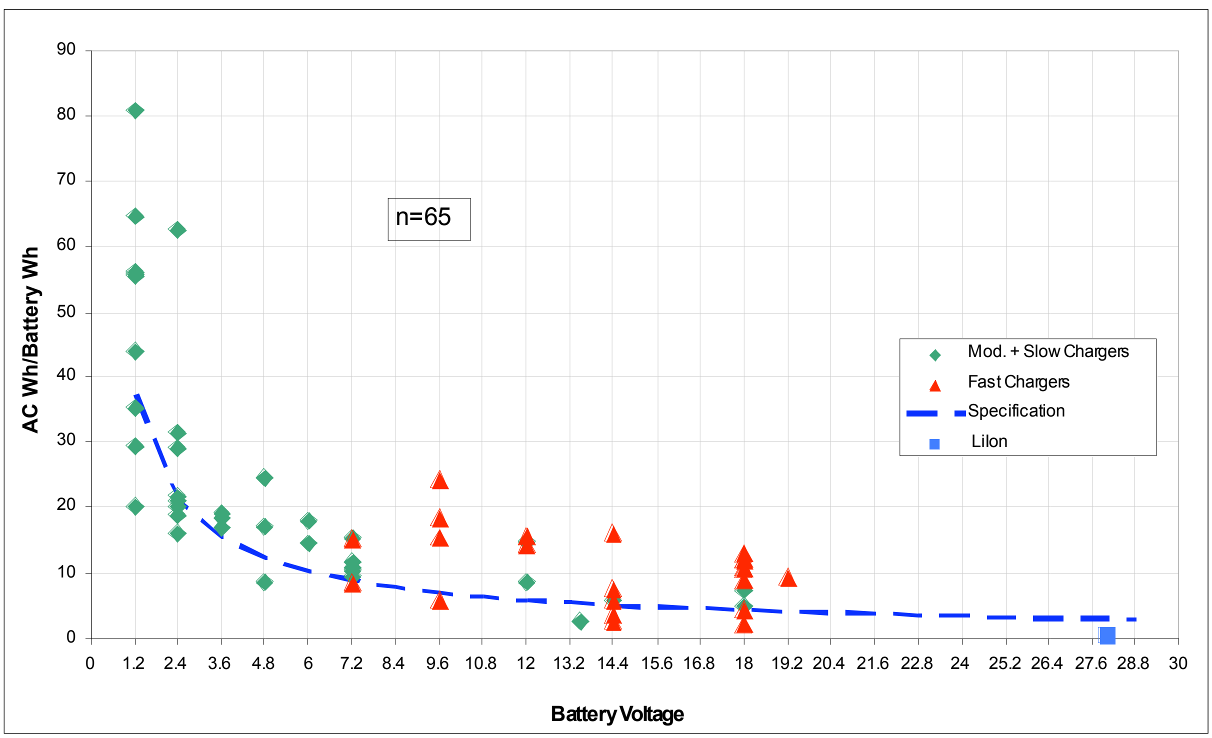
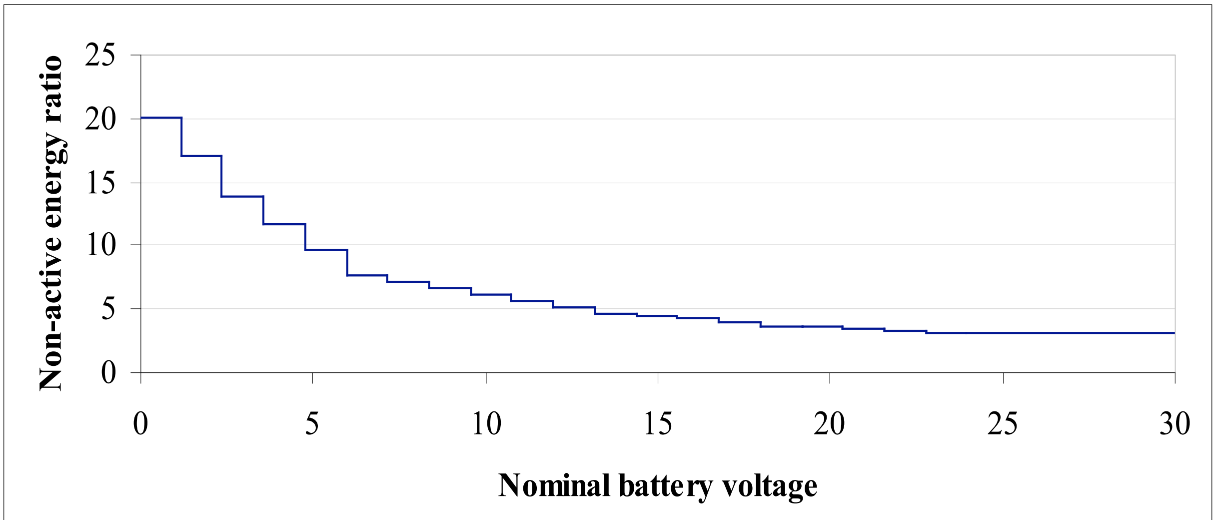


Figure 5. Energy Performance Criteria for Battery Charging Systems



One interesting aspect of the data emerged. Initially it was assumed that fast chargers with their smart circuitry and switch mode operation would always be more efficient than so-called linear chargers composed of simple transformers and diodes. Figure 4 shows that this is not always the case. Slow and fast charger populations clearly overlap in the data, with some slow chargers proving to be more efficient than fast, so-called smart chargers.

The ENERGY STAR specification for battery charging systems is based on the nonactive energy ratio, which is the ratio between the energy consumed by a battery charger over the course of its test procedure to the energy deliverable by the battery under known conditions (see EPA 2005 for more detail). Figure 5 shows the maximum nonactive energy ratios allowed under the specification for different nominal battery voltages.

State and Federal Standards. The California Energy Commission (CEC) approved minimum efficiency standards for external power supplies, scheduled to go into effect January 1, 2007 for laptop computers, mobile phones, printers, print servers, scanners, PDAs, and digital cameras. Other products are covered in July 1, 2007. The requirements are nearly identical to the ENERGY STAR Program requirements except that they

1) do not exempt the class of battery charged products exempted by ENERGY STAR
2) exempt medical devices regulated by the U.S. Food and Drug Administration
3) exempt power supplies sold as replacement or repair parts
4) do not require that devices be tested at European voltages (230 Volt).

In July of 2008, the standard will be tightened, with required efficiencies for the highest output devices increasing from 84% to 85%. Also, the maximum energy consumption in no-load mode becomes 0.5 watts for all levels of output power (CEC 2005). While the CEC is still holding hearings on the standard as of this writing, further changes seem unlikely.

California accounts for more than 11% of the US population and almost 13% of the gross national product. For classes of products where manufacturers don't wish to create entirely new models and maintain parallel product lines, the state regulation may effectively create a national quasi-regulation. It will markedly increase the penetration of ENERGY STAR devices in the market but will render the ENERGY STAR mark relatively meaningless for products with EPSs within the state.

At the national level, the Energy Policy Act of 2005 includes a provision for setting mandatory efficiency standards for external power supplies and battery chargers. The Department of Energy is currently scheduled to make a determination in 2008 of whether a regulation is practical. In the event of a positive determination the rule would be completed in 2011 with an effective date of 2014. The timing and outcome of this process is highly uncertain; it is possible that the final rule will be that no standard will be issued.

Savings Forecasts

Methodology

External power supplies and battery chargers are divided into a number of product classes both to improve the accuracy of the analysis and to single out certain products of particular interest to EPA. External power supplies are divided into laptops, LCD monitors, thermal and inkjet imaging, mobile phones, cordless phones (with and without an integral answering machine), MP3 players, personal digital assistants (PDAs), and digital cameras. Products not included in these breakouts are divided into seven categories according to output wattage. Battery chargers are divided into power tools, personal care devices (shavers, etc.), kitchen appliances, floor care (e.g., a hand vacuum), and "universal" chargers (for standard AAA, AA, C and D cell rechargeables).

At the core of the ENERGY STAR savings calculations is a stock accounting that calculates the number of ENERGY STAR units in place each year that can be attributed to the ENERGY STAR program. We segment sales of each product first into non-ENERGY STAR and ENERGY STAR units. Sales of ENERGY STAR-qualifying units are further divided into those that would have been sold even without the program (free riders) and those that can be attributed to the program. Product metering (Cadmus Group 2005; Reeder 2004) was used to estimate the market share of units meeting ENERGY STAR efficiency levels prior to the launch of the program.

For both external power supplies and battery charged household products, we assume that, in the absence of the program, product efficiencies would remain approximately the same as prior to the program. In the absence of informational labeling, or in fact any consistent test procedure for measuring and comparing efficiencies, there was little incentive to include efficiency in product design. Greater efficiency was a side effect of market trends for smaller, lighter power supplies for greater portability and convenience (large plug-in power supplies can block adjacent outlets); however, we believe that this trend has largely played out and is captured in our characterization of baseline efficiency.

Our estimate of ENERGY STAR program savings is for sales of high-efficiency units attributable to the program. Because the impacts of the program are highly uncertain at this early stage, we analyze six market penetration scenarios:

1) ENERGY STAR only, low growth
2) ENERGY STAR only, medium growth
3) ENERGY STAR only, high growth
4) ENERGY STAR, medium growth + California standards (state effects only)

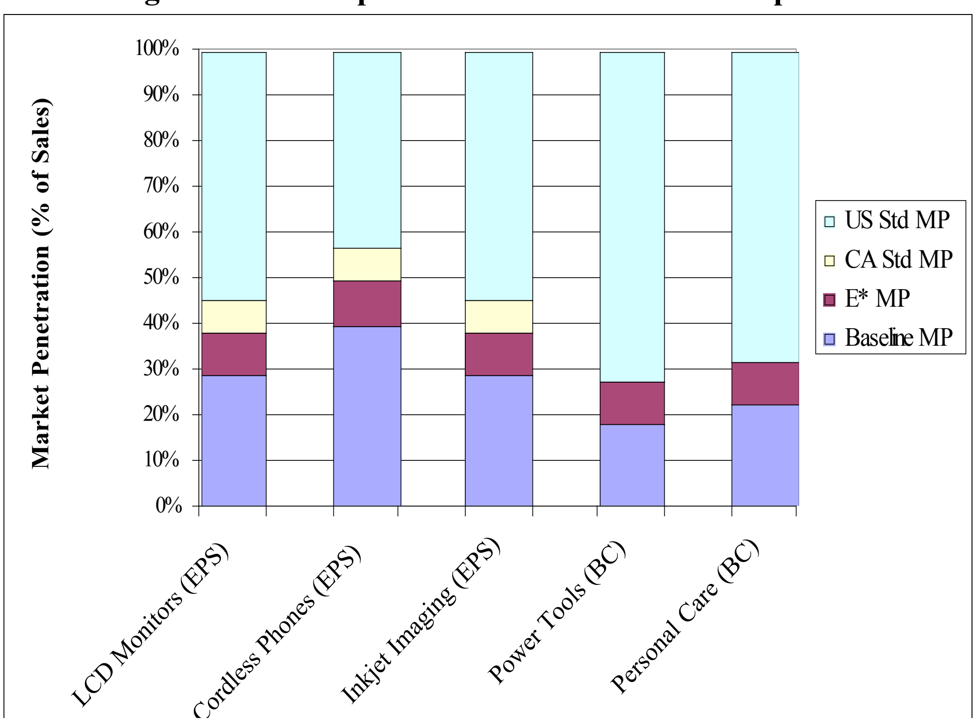
5) ENERGY STAR, medium growth + California standard becomes quasi-national standard
6) ENERGY STAR, medium growth + California standards + U.S. standards

California standards are assumed to begin in 2008 as scheduled. For simplicity, the impacts of California's second tier (2008) standards are ignored, as is the exemption for medical devices. The quasi-national standard effects of scenario 5 are assumed to ramp up more slowly than an actual national standard to a 90 percent market penetration. U.S. standards are assumed to go into effect in 2014 and achieve 100 percent market penetration.

Baseline market penetrations are based on market penetration in the years prior to the launch of the ENERGY STAR specification. For 2005 and 2006, ENERGY STAR is given credit for any increases in market penetration nationwide, including California. After 2007, all incremental California market penetration is attributed to state standards, with ENERGY STAR taking credit for increases in the other 49 states. Because the EPA and the California Energy Commission were both involved at a very early stage in developing test procedures and working with manufacturers, these programs continue to receive their full measure of credit for increases in market penetration, even after U.S. standards go into effect. Figure 6 shows market penetrations for select products in 2015 under scenario 7 by policy type (in the absence of California standards, ENERGY STAR market penetrations would be about one percent higher).

We subtract baseline market pentrations from total penetration to estimate the effect of the policies, then multiply by total shipments in each year to get incremental shipments of ENERGY STAR products. We apply a simple retirement model to calculate the number of ENERGY STAR units in place in each year (due to the policies). Devices are assumed to remain in place and accrue savings for a period equal to the average lifetime of the product,[1] and then are retired.

Figure 6. Market penetrations in 2015 for select products



[1] Product lifetimes are derived from a variety of sources, notably Appliance (2004)

Because the unit energy savings (UES) for some products change over time, we cannot simply multiply the number of ENERGY STAR units in place in each year by a single UES to get aggregate annual energy savings. Instead, we calculate the energy savings for each year's ENERGY STAR sales and then use our retirement function to add up the savings for all the equipment vintages in place in a given year.

Results

Table 1 shows the savings in 2015 for each of the six scenarios by product category. Estimates range from 1.1 TWh for ENERGY STAR alone to 12.4 TWh assuming the California standard for power supplies becomes a quasi-national standard (these savings are higher than the U.S. standards scenario in 2015 because the earlier start date means that a larger share of the stock has turned over). By 2025, that range opens up to 2.4 TWh for ENERGY STAR (scenario 1)

Table 1. Energy Savings in 2015, by scenario and product category (million kWh)

	2015 Stock[a] (000)	Unit Energy Savings (kWh/yr)	Slow Growth E* Only	Med. Growth E* Only	High Growth E* Only	Med. growth E*+CA stds (CA effect only)	Med. growth E*+quasi-national CA std	Med. growth E*+CA stds+US stds
Battery Chargers								
Power Tools	113,700	15.9	70	122	225	122	122	465
Personal Care	56,941	3.4	10	17	33	17	17	104
Kitchen Appliance	36,519	2.9	4	7	13	7	7	27
Universal Battery	7,814	7.4	3	5	9	5	5	22
Floor Care	33,165	1.3	2	3	5	3	3	11
Subtotal BCS	*248,139*		*88*	*154*	*285*	*154*	*154*	*630*
External Power								
LCD Monitor	90,172	50.1	296	535	1,014	873	3,538	2,430
Cordless phone	175,467	18.5	167	300	567	502	2,001	1,084
Combo phone/ans mach.	112,669	24.5	147	265	500	443	1,848	1,148
All other 2.5-4.5W[b]	168,844	10.8	98	177	335	296	1,089	607
Imaging devices, Inkjet	67,043	21.7	82	147	277	251	1,058	581
All other 10-24 W	89,569	15.7	75	133	249	243	1,024	492
All other <2.5W[c]	101,422	13.2	56	99	185	175	739	389
Computer Laptop	57,170	11.7	47	86	162	140	566	389
Mobile Phone	190,078	2.7	25	45	85	70	269	304
All other 4.5-6 W[d]	19,308	4.6	5	10	18	17	49	27
All other 6-10 W[e]	11,301	6.5	5	9	16	16	68	37
Imaging devices, Thermal	4,441	12.4	2	4	8	7	30	21
PDA	31,389	0.4	1	1	2	2	6	5
MP3 Player	27,362	0.5	1	1	2	2	6	6
Digital Cameras	5,749	0.9	0	1	1	1	3	2
All other 24-49 W	166	1.8	0	0	0	0	0	0
All other >49 W	99	0.0	0	0	0	0	0	0
Subtotal EPS	*1,152,249*		*1,007*	*1,812*	*3,422*	*3,039*	*12,294*	*7,522*
Grand Total	1,400,389		1,095	1,966	3,707	3,192	12,448	8,153

[a]This is the stock of each device type that has an external power supply. The stock includes free riders, which are not counted toward savings in any scenario.
[b]Includes computer speakers, hubs and modems, among other equipment.
[c]Includes other powered phones and phone accessories (headsets, etc.), scales, KVM switches, laptop docking stations, and dictation equipment.
[d]Includes routers and credit card readers
[e]Includes LAN switches and home security systems.

Table 2. Savings from Four ENERGY STAR Specifications

	Program Start Year	Savings in 2015	Savings in 11th Year of Program
Central Air Conditioners	1995	0.42	0.53
Commercial Refrigeration	2001	1.3	0.80
Water Coolers	2000	2.2	1.5
Televisions	1998	22.6	8.5

and 17 TWh for the U.S. standard scenario. External power supplies make up the vast majority of savings, with external power supplies for LCD monitors, cordless phones and combination phone/answering machines making up over half of total savings in 2015. Also included in Table 1 are equipment stocks and unit energy savings in 2015.

To put these results in context, Table 2 shows savings for a range of established ENERGY STAR products that have had a chance to gain market share. Savings are shown for both 2015 and for the eleventh year of operation of the program (in 2015, the external power supply specification will be in its eleventh year and the battery charger specification in its tenth).

Figures 7 and 8 plot the trajectory of savings for each market penetration scenario from 2005 to 2025 for external power supplies and battery charging systems, respectively. The two standards scenarios show initial steep growth followed by a flattening of the curve once the stock in the impacted region has turned over. There is a wide spread between the slow and high growth ENERGY STAR scenarios that reflects the large uncertainties in how that program will evolve. By 2025 the spread is about 6 TWh for external power adapters and 0.6 TWh for battery charging systems.

Figure 7. Energy Savings for External Power Supplies (TWh)

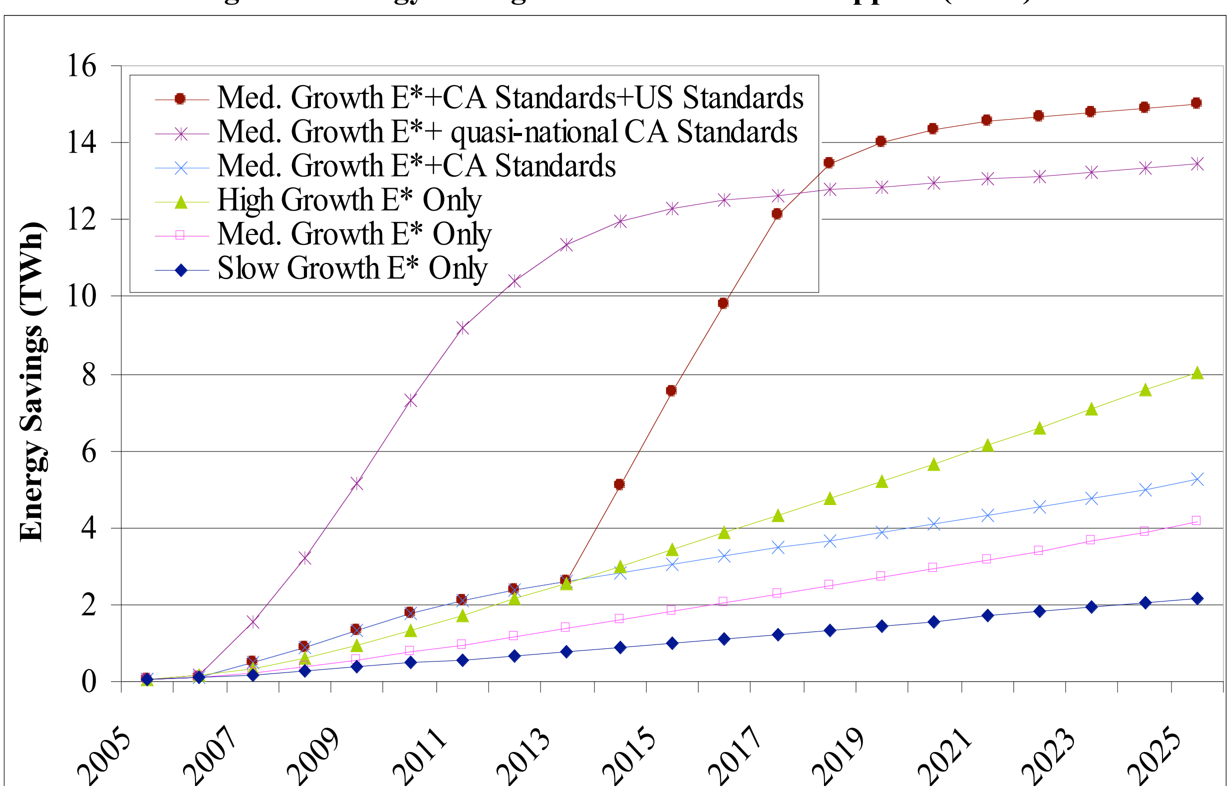
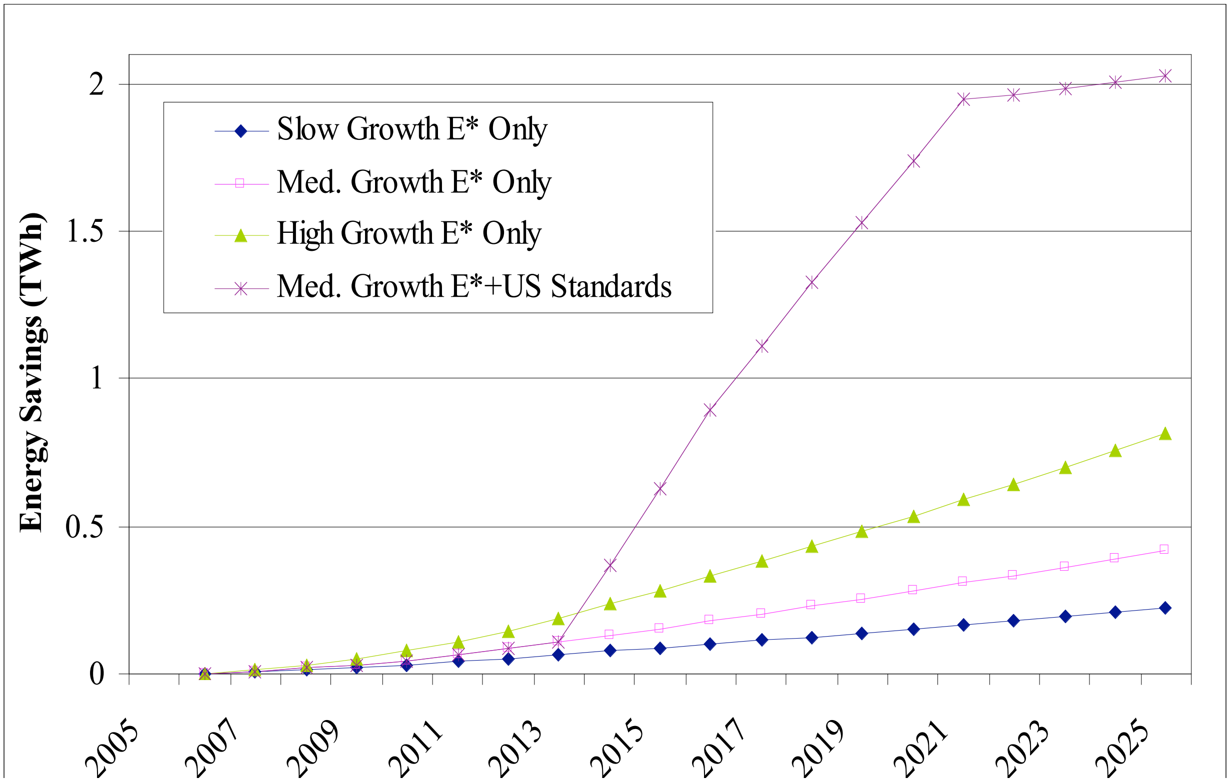


Figure 8. Energy Savings for Battery Charging Systems (TWh)



Conclusions

Even with modest gains in market penetration, the ENERGY STAR external power adapters and battery charger programs are expected to save a cumulative 1.5 TWh of electricity between 2005 and 2010, increasing to 24 TWh by 2025. With slightly higher market penetrations and the additional impact of California standards, savings increase to 64 TWh through 2025, even assuming no spillover effects from California standards. Adding a U.S. national standard could save 180 TWh over the same period.

These savings will take a significant bite out of energy use by electronic devices over the coming years. And because these policies are broadly defined, new electronic gadgets entering the market will find these new policies will be in place waiting for them.

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